WPS5955

Policy Research Working Paper 5955

Allocative Inefficiencies Resulting from Subsidies to Agricultural Electricity Use

An Illustrative Model

Jon Strand

The World Bank
Development Research Group
Environment and Energy Team
January 2012

Policy Research Working Paper 5955

Abstract

This paper provides an analytical discussion of several interconnected resource allocation problems from under-pricing of electricity used by farmers for groundwater extraction. In these situations, groundwater extraction is inefficiently high even without electricity under-pricing. Moreover, part of the electric power supply intended for farmers is often diverted to other unauthorized uses (notably illicit consumption). The paper demonstrates that unless non-price electricity rationing imposes severe constraints on demand, the range of resource allocation problems includes insufficient incentives to provide high-level service by the power utility, insufficient incentives for farmers to install and operate efficient equipment, and losses due to political "rent seeking" activities to influence water allocations. It also shows that diversion of electricity to illicit uses can increase overall economic efficiency when this leads to less electricity use by farmers, thus somewhat ameliorating the problem of excessive groundwater extraction as well as the inefficiencies related to under-pricing of electricity. Systemic reforms for overcoming these problems may face severe political obstacles.

This paper is a product of the Environment and Energy Team, Development Research Group. It is part of a larger effort by the World Bank to provide open access to its research and make a contribution to development policy discussions around the world. Policy Research Working Papers are also posted on the Web at http://econ.worldbank.org. The author may be contacted at jstrand1@worldbank.org.

Allocative Inefficiencies Resulting from Subsidies to

Agricultural Electricity Use:

An Illustrative Model *

By

Jon Strand

Development Research Group

Environment and Energy Team

The World Bank

Jstrand1@worldbank.org

JEL classification: Q25, Q28, Q41, Q48

Key words: Agricultural water use; electricity subsidies; groundwater extraction; water allocation inefficiencies; rent seeking.

Sector Board: Environment

Project codes: RF-P123604-RESE-BBRSB (RSB project); P126330 (KCP project)

* *This paper has been prepared as part of a larger research program in the Development Economics Group, energy subsidies and their allocational, distributional and fiscal implications. I thank Stefan Csordas for very helpful comments to a preliminary version. This research was carried out partly under the KCP project "Electricity Subsidies and Groundwater Extraction by Indian Farmers: Implications of Energy Subsidy Reform for Economic Efficiency and Distribution", and partly under the RSB-financed project "Political Economy of Energy Subsidies and Their Reform". The views expressed in this paper are those of the author and not necessarily those of the World Bank, its management, or its member countries.*

1. Introduction

This paper seeks to discuss interactions between several types of distortions resulting from subsidized electricity to agriculture, in cases where distortions related to the over-extraction of groundwater used for agricultural production interacts with other types of distortions. The idea is to draw some conclusions about the nature of the main distortions, how they can be alleviated, and what policies are in case required. The basic problem scenario to be discussed involves the following main issues:

1) Under-pricing of electricity to farmers, leading to generally inefficient use (over-use and/or rationing with differences in users' marginal valuations).
2) Most of the electricity is used for extracting groundwater. Very likely, such extraction is socially excessive; this problem is compounded by a common-pool problem related to groundwater extraction.
3) Connected to under-pricing is the fact that electricity is supplied erratically and inconsistently (during only part of the day; perhaps not every day; and with erratic charge). In consequence, many or most agricultural consumers are effectively rationed, and the allocation of electricity supply across users and user groups, and for a given user, is inefficient.
4) There is illicit extraction which reduces the amount of electricity available for legal supply. The resulting consumption may go toward general household supply, or to agriculture; but perhaps mostly the former.
5) Under-pricing of electricity by power utilities leads to sub-par incentives to provide good supply by the same entities. This is, in part, the direct cause of the problem under point 3.
6) Under-pricing of electricity adversely affects the efficiency of electricity use among agricultural consumers. Depending on circumstances, this could result in either excessive or deficient private investments in equipment to be used for extracting groundwater, such as pumps and tube-well construction.
7) Inefficient cropping patterns including general choice of too water-intensive crops.

Such issues have been subject to substantial analysis and discussion, much of it in the context of Indian agriculture, focusing in particular on the problem of excessive groundwater extraction in Northern India, and distortions of crop choices in that context. Some key reference studies are Briscoe and Malik (2006), Banerji et al (2006), Ray (2008), Reddy (2005), Shah (2009), and Vaidyanathan (2006). Additional discussion of electricity issues for the agricultural sector is provided by Dubash (2005a, b), and Ramachandra Murthy (2009). See also the newly released World Bank (2010) study discussing a variety of measures against excessive groundwater extraction. This literature generally stresses that low electricity prices to the agricultural sector in India is a major factor behind this excessive groundwater extraction, which currently affects between 15 and 25 percent of Indian agriculture (World Bank 2005, 2010). If nothing is done to correct current developments, there could be drastic consequences for a large share of India's population, in years with only rather marginal natural water scarcities. A more recent study by Birner et al (2010) provides an extensive discussion of political economy aspects of the "energy-groundwater nexus", with particular application to India.

The World Bank (2010) and Birner et al (2010) studies indicate a number of policy measures that can be used to help reduce the problem of excessive groundwater extraction. These measures would be broadly applicable wherever conditions like those in India arise. The World Bank (2010) study argues strongly that if nothing is done with incentives for groundwater pumping involving extremely cheap electricity (typically, only a fixed fee per farmer and no volumetric charges), increasing strains on groundwater resources will be extremely hard to reverse. Both studies recognize that the problem is exceedingly hard to deal with politically. In situations like those in India that are addressed in these studies, many poor farmers are highly dependent on cheap electricity for their normal crop output, even though a substantial share of the overall electricity allocation goes to well-off farmers. Low electricity costs for farmers is part of a "social contract" whereby one group of farmers rely on (near cost free) surface irrigation water, and another group which relies on pumped groundwater. While this represents an "even circle" of sorts, there are serious problems with attempting to upset the balance between these two groups of farmers (such as charging for electricity from one group without charging for surface water from the other group). Thus, the problem seems today to have few "easy fixes".

We should however note that some researchers, notably Birner et al (2010), open up for a more nuanced view on the main driving forces behind the problems of excessive groundwater extraction. These authors stress two main, competing, viewpoints: the "market-oriented discourse", and the "welfare-state discourse".[1] Under the former, the argument runs essentially as above: low electricity pricing is the main problem. Under the "welfare-state discourse", low electricity pricing to farmers is not seen as the main cause. Rationing of farmers' water extraction (via rationing of their electricity supplies) is instead considered sufficient to keep effective water demand at a "reasonable" level (by this is typically meant a level equivalent to demand given a "normal" electricity price, in the absence of rationing). Their argument is that farmers use the water they "need", for the cropping patterns chosen. The basic problem, it is argued there, is instead inefficient crop choice, as illustrated in the Indian context by the government's encouragement of paddy cultivation. This argument may clearly have some bite: water-intensive crops such as paddy and sugar cane, grown extensively in Northern India, are substantially more water intensive than many other relevant (and higher-value) crops.

In the model developed below, sufficiently strict rationing of electricity supply to farmers could in principle (but only as a special case) implement an overall optimal level of groundwater extraction, even in the absence of electricity pricing. We will however see that other inefficiencies will then usually result, including inefficient distribution of electricity supply (and water extraction) across farmers, and substandard power supply service including excessive system losses. An important caveat is that the discussion in this note will focus less on political economy problems of the types stressed in the World Bank (2010) and Birner et al (2010) documents, and more on economic issues in particular related to allocation and efficiency, including how to identify sources of "allocation loss" relative to benchmarks. Importantly, distributional considerations are sidestepped.

Our formal analysis will also be less centered on agricultural issues such as crop choice and irrigation patterns and practices, even though such underlying issues are at the heart of the problem (in particular, issues pertaining to point 7 above will not be dealt with). These issues are discussed only in a summary way, by simply defining a marginal value function for water as used in the agricultural sector. In addition, there is also no substantial discussion of the

[1] Birner et al (2010), pp 146-147.

basis for the groundwater extraction externality (represented by the “shadow price” parameter h in the following). Such a discussion is included in a separate note, Strand (2010).

2. The basic optimality model

The simple model dealt with in sections 2-5 focuses on points 1-4. Additional points will be addressed in the expanded model of sections 6-7. Consider a region where the number of farmers eligible for low-price electricity supply is given and normalized to unity. Assume that these farmers can be sorted into two groups: group 1 where water value and demand are “low” at “normal” consumption levels (fraction of consumers in this group equals β); and group 2 where water value and demand are “high” (fraction of consumers in this group equals 1-β). The main difference between the two groups is that only the latter will be assumed to be effectively rationed in cases with low electricity prices. Utility functions as fraction of available farmers in the two groups are $V_1(E_1)$ and $V_2(E_2)$ respectively. E is total electricity supplied (and targeted at the agricultural sector). α is the share of electricity “lost” either due to illicit use or to transmissions losses. We assume that one unit of electricity used for pumping results in one unit of groundwater extracted, which is the basic production factor going into agricultural production.[2] Our assumption in the following is that electricity that does not reach farmers, αE, is all used but not by intended users and not paid for. E_1 and E_2 are amounts of electricity consumed by each of the two specified groups of farmers. We can then write

$$E(1-\alpha) = E_1 + E_2. \tag{1}$$

Assume that all electricity is produced by a public power utility at constant marginal cost c. Assume also that the marginal social opportunity cost of groundwater extraction is constant per extracted water unit, including the cost of pumping, and equals some number h > 0. The parameter h consists of two parts: one “private” part which is pumping cost per unit of water used in agricultural production; and one “social” part which is the pure shadow value of groundwater left in the aquifer.[3] Both c and h are likely to vary across regions; c varies with production technologies in the power sector (and because there is not sufficient inter-regional capacity to secure a unitary national electricity price); and h varies because the seriousness of the groundwater extraction problem, and the depth to the water table in the aquifer, is greater in some regions than in others.

Consider now the optimal allocation of electricity between the two agricultural sectors and also to “illicit use”, and where the value of electricity consumption for illicit users is assumed given by the (increasing and strictly concave) function G(αE). The objective function to be maximized is then

[2] In practice, the amount of electricity required for pumping one unit of groundwater is roughly proportional to the depth to the water table. In the presentation here we ignore this issue and assume that the water table level is given, and constant, over the period for the analysis. For further discussion of such issues see Strand (2010).

[3] In the context of a model where farmers would pay for electricity at delivery cost, the “private” value part needs not to be included here, only the “social” part. Here, however, the point of departure is zero electricity pricing so that farmers have no incentive to take this “private” part into consideration in their production decisions. Moreover, assuming as here that pumping cost per water unit is a constant, it is appropriate to assume that h is a constant across farmers. On the other hand, when groundwater depth varies across relevant aquifers, the issue is more complex; then h must be viewed as a weighted average across the relevant farmer populations.

(2) $$U = V_1(E_1) + V_2(E_2) + G(\alpha E) - h(1-\alpha)E - cE$$

Maximizing (2) with respect to E_1, E_2, E and α (given the constraint $E_1 + E_2 = (1-\alpha)E$) yields the following solutions:

(3)-(4) $$V_1' = V_2' = c + h$$

(5) $$G' = c.$$

By (3)-(4), optimality implies that the marginal value of electricity use should be equal for both user groups, and both should equal the total marginal cost of electricity use, comprised of the marginal production cost, c, and the marginal extraction cost for groundwater, h. By (5), the marginal benefit for illicit users should be equal to marginal production cost only (and thus lower than for agricultural electricity users).

It may here seem unusual for an optimal solution to entail illicit consumption, here for electricity and possibly in substantial amounts. But the direct conclusion from the model is even stronger: Given the model assumptions, it is optimal for the "illicit" market to enjoy "more" electricity than the regular market (in the sense that the marginal utility of electricity consumption should be lower for illicit use). For a given supply of electricity from the power utilities, the allocation loss is less when more of this electricity goes to illicit users, and less to farmers. The reason for this is that the only difference in our model between illicit and agricultural electricity users is that only the latter and not the former imposes a negative externality due to additional groundwater extraction (since, it is assumed, illicit users do not extract groundwater). This assumption could be misleading. Other assumptions may also be questioned: since illicit users are not charged, it is not known who has high and who has low values of consumption. We are also abstracting from illicit user costs, and ignoring fairness and distribution arguments (it can perhaps be argued that a party that steals a commodity has no right to it; this is however no particular argument here). Finally, we are ignoring the problem that implementing the efficient allocation of electricity consumption among illicit users is practically impossible. This is because these users are not charged a price for the electricity that they consume.

We also assume that the power utility is unable to directly separate its supply to farmers from its supply to illicit users; given fractions go to each of the two groups once basic power is supplied. Efficiency here of course requires that these be fully separated, and independently charged.

3. Equal power allocation to all agricultural consumers

We will now compare the solution in the simple optimization model above, to a case where electricity is allocated equally to all agricultural users. This implies that

(6) $$E_1 = \beta(1-\alpha)E,$$

(7) $$E_2 = (1-\beta)(1-\alpha)E.$$

Inserting this into (2) and differentiating with respect to α and w now yields (5), plus the additional condition

(8) $$\beta V_1'(\beta(1-\alpha)E)+(1-\beta)V_2'((1-\beta)(1-\alpha)E)=c+h$$

The only difference between (8) and (3)-(4) is that there is now a fixed relation between the relative electricity consumption levels of groups 1 and 2 such that each consumer has the same share of the total electricity supply. We have here assumed that group 1's value of such an allocation at the margin is negligible; while group 2's value is high. As an approximation we set $V_1' = 0$ so that

(9) $$(1-\beta)V_2'((1-\beta)(1-\alpha)E)=c+h.$$

We now see more sharply the difference between the two cases: The marginal utility of electricity consumption to consumers with "high" value is now increased by a factor of 1/(1-β) relative to the solution in (4), for a given level of electricity supplied, E. The idea is to mimic a more realistic solution in this case, than that given by (3)-(4). In the previous case we assumed, unrealistically, that electricity was allocated efficiently across all consumers, despite no positive price of electricity being charged of any consumer. It is then instead realistic that the marginal value of consumption (which is, typically, rationed for all consumers) varies across consumers. This leads to an allocation loss relative to the efficient solution where all marginal utilities are the same.

Note also that with solution (9), it is required that the return to "high-value" farmers is very high, and may be unrealistically so. Remember that these farmers still pay nothing for the electricity they receive; the only allocation mechanism to ensure such a high return is rationing of overall supply. The main point to be made with this case is then that, when V_2' is at a given level for both cases, the rigidity of supply depicted here (whereby all consumers are given the same water allocation) implies additional inefficiencies.

4. Fixed electricity allocations

Consider next a case where the overall supply of electricity, E, is exogenous, identified as the (maximum free) electricity supply promised to farmers; and α (the fraction of the electricity intended for farmers but going instead to illicit users) is also given. Since electricity is provided for free to farmers, we presume (as before) that $V_1' = 0$ (the marginal value of electricity supply for "low-value" farmers is zero). We also assume that $(1-\beta)V_2' = k < c+h$, where k (= the marginal gross value of electricity consumed by the agricultural sector in this case) is a fixed number. This amounts to an assumption that the overall marginal return to electricity for farmers in this (high-value) group, in a rationing solution, is less than the social opportunity cost of electricity going to farmers, c+h. While this assumption may appear plausible, it will not always be fulfilled when there is serious rationing. See in particular Banerji et al (2006) who argue that the optimal amount of irrigation water to (some sets of) farmers in Northern India may be inefficiently low (at least when the groundwater value is not accounted for). With our notation, we would in such cases have $V_2' > c$ for this group; when then both β and h are small our assumption may not hold. This would correspond to the story line under the "welfare-state-oriented discourse" in Birner et al (2010), where low electricity prices are not the root cause of any groundwater over-extraction problem. There would then however be no groundwater extraction problem: the problem would instead be too little extraction.[4] We disregard this possibility in the following.

It is here of interest to study implications of changes in E and α from an arbitrary, inefficient, starting point. We find:

$$\frac{dU}{d\alpha} = (G' + h - k)E \tag{10}$$

$$\frac{dU}{dE} = -(1-\alpha)(h + c - k) - \alpha(c - G') . \tag{11}$$

G'+h-k expresses the excess marginal net social return from increased electricity supply to illicit users rather than to agricultural users. This could be positive or negative. However, when h is high (there is a large negative externality from groundwater extraction), and k is low (farmers' return to electricity consumption is low at the margin), dU/dα could easily be positive. Some might view it as paradoxical that it is optimal to allocate less of a given electricity supply to legitimate (agricultural) consumers, and more to illegitimate ones.

In (11) the two main terms express the net return of electricity going to (legitimate) agricultural users, and to illegitimate users, weighted with the groups' fractions. The first is unambiguously negative (under our assumptions), and the second also most likely negative.

Note here that when some part of illicit electricity consumption, say a fraction γ, is used for groundwater extraction (compared to none of this consumption), we must replace G' by G'-γh which is lower and makes it more likely that both dU/dα and dU/dE are negative.

5. The effects of activities to influence the legitimate electricity share

We will next consider a case where "influence activities" (rent seeking, corruption, etc) play a role. Such activities could take many forms. One form would be corrupt diversion of electricity (for private gain by public officials) from legitimate to illegitimate users. Another, on which we focus here, is activity initiated by farmers to reduce the illegitimate share of electricity supply that was originally aimed at the agricultural sector. This may be a natural focus here, since such activity may be seen as not necessarily corrupt but rather as an integral part of the political process. The point is that a certain amount of electricity is assumed to be set off for agricultural users, but that only part of this electricity actually reaches its destination; another part is diverted, illegitimately. The activity taking place, to reduce this "drain", may then be fully legitimate.

Assume then that the parameter α is affected by effort, B, to increase the agricultural share of electricity supply, and thus to reduce the illicit share α (which could be viewed as losses by farmers, and perhaps also by the power utility). Efforts to reduce α could be exerted either by the agricultural sector, or by the power utility. Our view will thus be that B represents farmers' efforts (principally, those farmers in group 2, with a positive marginal value of

[4] As we however have already noted, there could be water over-extraction in the sense that crop choice of Indian farmers is inefficient and too water-demanding.

additional electricity). We assume that there exists a downward-sloping and strictly convex function $\alpha(B)$, $\alpha'(B) < 0$, $\alpha''(B) > 0$, primes denoting derivatives.

B could in principle represent physical effort by farmers, or money or goods transfers (bribes) from the agricultural sector to employees of the power utility. The form that B takes has welfare implications of this activity. When B is "effort", it is a social cost to be subtracted in a social calculation. When B is instead a transfer (bribe), it is not necessarily a social cost (as there is a corresponding benefit for the receiving party). We will as our main case assume that B is "effort" and thus a social cost.[5]

The new condition relative to the analysis in sections above is here the condition for optimization of net utility with respect to B, for farmers with positive marginal value of electricity. For these, the net utility function can now be written as

(12) $$V_2((1-\beta)(1-\alpha)E) - B,$$

which is maximized with respect to B to yield

(13) $$(1-\beta)EV_2'((1-\beta)(1-\alpha)E)\alpha'(B) = -1$$

(13) can be solved for B and thus for α (since all other parameters in (13) are exogenous). Comparing to a case with no influence activity, α should now generally be lower and the share of electricity $1-\alpha$ going to farmers higher. We can then ask what happens to welfare when such activity takes place. This in particular depends on the sign of $dU/d\alpha$ in (10). When this is positive, the induced reduction in α considered here has a *negative* welfare implication (there is a social loss when farmers get more of the electricity supply). Since B is a social cost, the overall welfare impact of influence activities is then negative. When $dU/d\alpha < 0$, it is socially advantageous to raise α. The overall welfare effect then depends on the value of this welfare gain, compared to the social cost of the influence activity itself, B.

To consider the welfare gain or loss resulting from such activity, assume that the "initial" value of α ("before influence activities") is set at α_0, and the value that solves (13) is $\alpha_1 < \alpha_0$. Then the (positive or negative) welfare change is given by

(14) $$\Delta U_1 = (G' + h - k)E(\alpha_1 - \alpha_0) - B.$$

The first main term in (14) is the net welfare gain associated with the induced (negative) change in α. Given that $G' > k-h$, implying that the marginal social return to illicit electricity consumption is greater than the return to regular agricultural electricity consumption, a higher α is socially gainful. A social loss is then incurred when α is reduced. Since there is an additional social cost B related to farmers' influence activities, the overall welfare effect is negative. When $G' < k-h$, the induced reduction in α is socially gainful when the costs of influence activities, B, are disregarded. Since there however is such a cost, the overall welfare effect is ambiguous.

[5] One should note that even when B is a transfer, it may still often be appropriate to consider such expenditure as a social cost, at least in part, as due to distributional or moral considerations, or since such payments tend to have adverse allocational implications at least in the long run (one being that highly qualified personnel are attracted to such activity, instead of to other activity where their net social returns are higher.

A similar analysis could here have been added whereby influence activities are exerted also by illicit consumers, in the form of either bribing public servants into increasing the illicit consumption share α, or exerting effort to extract the illicit electricity. Using a similar argument as above, the welfare effect of such activity could on net be positive or negative. When the influence activity is bribing, the welfare effect of such activity is positive given that G' > k-h, as was assumed above to be likely. When the influence activity is effort by illicit users, welfare may increase or go down depending on whether the following expression is positive or negative:

(14a) $$\Delta U_2 = (G' + h - k)E(\alpha_2 - \alpha_0) - H ,$$

where α_2 is the new (and higher) level of α, and H represents influence costs in this case. This expression is likely to be positive when H is small, and negative when H is great.

Note finally that when both B and H are exerted simultaneously (as is likely to happen in practice), α is affected in opposite directions. A simple case is where α is unaltered by such activities. If the activities then have not influence on overall electricity supply intended for farmers, E, the net welfare effect of the influence activities is unambiguously negative given that B+H > 0 (so that either influence activity is costly).

6. Optimality in an expanded model

We now go back to the basic model of sections 2-3, with an optimal allocation of electricity supply and consumption given three sets of consumers ("low" and "high" value agricultural users, and illicit users), expanding the model somewhat relative to previous sections. We now ignore the influence activities of the previous section, as these are "coping" (and, typically, inefficient) strategies that would be redundant under an optimal allocation. We instead introduce three new features.

The first new feature is "supply quality". By this we simply mean the utility gain that legal consumers (farmers) obtain from a given power supply, and that this "quality" can be influenced by the power utility. Supply quality can vary e.g. as supply is more or less reliable, predictable, stable and continuous, with correct and constant voltage, etc. Failures in these respects may imply that the value of a given amount (number of kWhs) supplied is lower than otherwise. A simple way to represent this is to introduce a shift parameter τ into the value functions for electricity, for the two agricultural consumer groups 1 and 2, so that these values are τV_1 and τV_2 respectively. Positive shifts in τ are achieved at effort cost, Z, incurred by the power utility and its employees, so that τ(0) = 1 ("no extra effort" by the utility; the status quo situation described above), τ'(Z) > 0, and τ''(Z) < 0 so that there is decreasing marginal return to such efforts. Note that with this definition of supply quality, changes in this variable do not by themselves affect groundwater pumping for given basic electricity supply. We also assume that the quality of power supply to illicit consumers cannot be affected by such activities.

The second feature is power utility effort to reduce the share α of illicit power consumption, incurring a cost Q. This is related to "influence activity" in section 5 (in the sense that α is affected endogenously in both cases), except that the mechanism by which α is affected is different.[6] This entails a function α(Q), where α'(Q) < 0, α''(Q) > 0.

Thirdly, agricultural power consumers can take action to increase the value of the given electricity supplied to them. Since by assumption, all electricity supply to agriculture is used for pumping groundwater, greater pumping efficiency on the side of farmers enables them to produce more agricultural output on the basis of a given amount of electricity consumed; e g through more efficient or rational pumping activity, and better and more economical pumps.[7] This is here simply modeled such that greater agricultural efficiency in using electrical power implies a proportional increase in the amount of groundwater extracted. In the model, these effects are represented by the functions $\varphi_i(C_i)$, i = 1,2, as multiplicative factors to W_i in the utility functions for electrical power to agricultural group i, and where C_i is the cost of implementing an efficiency improvement (such as installing more efficient pumps, etc.). We assume that the φ function is increasing and strictly concave, so that $\varphi_i' > 0$, $\varphi_i'' < 0$.

A related issue interacting with this last extension of the model (but which does not directly enter into the model) is that as the groundwater table falls and pumping becomes more demanding and energy intensive, it also becomes necessary with heavier and more expensive pumping equipment. Such concerns will arise in a modeling context given that one studies developments over time with variable (falling or rising) groundwater table levels (and degrees of replenishment of basic groundwater).

A first-best solution is in this case found by maximizing the following utility function:

(15)
$$\begin{aligned}U &= \tau(Z)V_1(\phi_1(C_1)E_1) + \tau(Z)V_2(\phi_2(C_2)E_2) + G(\alpha(Q)E)\\ &-h[\phi_1(C_1)E_1 + \phi_2(C_2)E_2] - cE - Z - Q - C_1 - C_2\end{aligned}$$

subject to the constraint $E_1 + E_2 = (1-\alpha)E$). We form the following Lagrangean:

(16)
$$\begin{aligned}L &= \tau(Z)V_1(\phi_1(C_1)E_1) + \tau(Z)V_2(\phi_2(C_2)E_2) + G(\alpha(Q)E) - h[\phi_1(C_1)E_1 + \phi_2(C_2)E_2]\\ &-cE - Z - Q - C_1 - C_2 - \lambda[E_1 + E_2 - (1-\alpha(Q))E]\end{aligned}$$

A "first-best" solution here entails deriving first-order conditions of L with respect to E_1, E_2, E, Z, Q, C_1 and C_2. We find the following set of equations:

(17)-(18)
$$\frac{\partial L}{\partial E_i} = \tau\phi_i V_i' - h\phi_i - \lambda = 0\text{, i = 1, 2}$$

(19)
$$\frac{\partial L}{\partial E} = \alpha G' - c + \lambda(1-\alpha) = 0$$

[6] In our model below, α is set to optimize the objective function of a benevolent planner. Alternatively, we could here model α as being affected by incentives (reward functions) facing power utility employees.

[7] An additional way in which efficiency in electricity use can be improved is via better crop choice by farmers. This interpretation is however not emphasized here because of the way in which efficiency in electricity use also enters into the water extraction function (as proportional to water extraction).

(20) $$\frac{\partial L}{\partial Z} = \tau'(V_1' + V_2') - 1 = 0$$

(21) $$\frac{\partial L}{\partial Q} = EG'\alpha' - 1 - \lambda E\alpha' = 0$$

(22)-(23) $$\frac{\partial L}{\partial C_i} = \tau E_i V_i' \phi_i' - hE_i\phi_i' - 1 = 0 \text{, i = 1, 2}$$

Given internal solutions for all variables (see below), the 7 equations (17)-(23) plus the budget constraint for electricity give 8 conditions to determine the 8 endogenous variables E_1, E_2, E, Z, Q, C_1, C_2 and λ (as, in particular, α is given directly by its functional relationship to Q).

These conditions permit us to derive the following marginal optimality conditions:

(24)-(25) $$\alpha G' + (1-\alpha)\phi_i(\tau V_i' - h) = c \text{, i = 1,2}$$

(26)-(27) $$\tau\phi_i V_i' = \phi_i h + c - \frac{\alpha}{E\alpha'} \text{, i = 1,2}$$

(28) $$G' = c + \frac{1-\alpha}{E\alpha'} < c$$

(29)-(30) $$\phi_i' = \frac{1}{E_i(\tau V_i' - h)} \text{, i = 1,2.}$$

In interpreting these conditions, (24)-(25) are essentially the same as conditions (3)-(4) in section 2. (26)-(27) state that the marginal value of electricity consumption for agricultural consumers of either type, on the left-hand side, is to equal the sum of the "effective groundwater extraction externality" per unit of basic electricity consumption, $\varphi_i h$, plus the power supply cost c, plus a term that reflects the additional cost of increasing electricity supply to farmers through diversion away from illicit use.

(28) states that optimal illicit electricity consumption is dimensioned such that marginal value to illicit users equals marginal electricity provision cost c, minus a term that depends on the α function. In particular, G' should take a lower value here than in the simple model of section 2. This implies a larger allocation of electricity to illicit consumers. This may seem surprising but has a simple explanation. In section 2, we assumed that it was possible to find a direct optimum with respect to G, at no particular cost. Here this is assumed not to be the case: instead one must resort to expensive diversion activities in order to implement the (constrained) optimal G. Assuming then that G "starts" at a higher level (and G' at a lower level, in the absence of any diversion activities) than the final equilibrium level, (28) provides the (constrained) optimal final solution for G. Or in other words, it is not optimal to push illicit use all the way down to the (unconstrained) optimal level that was found in section 2, since this is costly.

This analysis however raises the question of what happens in the model if the "starting value" for G (with Q = 0) is below the final value to be derived from (28). In such cases we have a corner solution with this particular G value, and Q = 0. It is then not socially beneficial to divert electricity away from illicit use, since the marginal return to electricity use is no higher in the agricultural sector. It is rather optimal for the power utility to divert more of a given electricity output away from farmers and onto "illicit" consumers.

From (29)-(30), the equilibrium marginal value of electricity enhancing effort (φ_i') is inversely proportional to the marginal social gain from such effort (τV_i'–h). This implies that this effort increases in step with its marginal social gain. A higher h here leads to lower φ_i' and thus higher C_i.

The solution just derived remains a hypothetical target insofar as no effective means of implementing it is specified. Implementation would in general require a) that farmers face electricity prices equivalent to marginal social costs; b) that the same users be charged for efficiency improvements (increases in φ_i) that lead to greater groundwater extraction for given electricity consumption; c) that "illicit" electricity consumers be charged the net social cost of their consumption at the margin; and d) that the power utility must be provided incentives to itself implement efficient levels of both E (thus exerting effort to improve service quality to agricultural consumers) and Q (exerting effort to prevent illicit electricity consumption). While a) is thinkable in principle (but not likely to be politically realistic), b) and c) are difficult to visualize even as in principle (c even an absurdity). d) is also very difficult to visualize as a practical solution, as a proper set of optimal incentives (with two independent instruments) need to be applied to the power utility itself.[8]

The solution may however still be useful as a benchmark with which to compare a practical solution, and measure the degree of inefficiency (relative to this hypothetical target).

7. Zero electricity pricing and rationing in the expanded model

We noted that the analysis in section 6 is grossly unrealistic when applied to an agricultural sector such as that in India, mainly because it does not account for the fact that electricity is, basically, not paid for at the margin by farmers. The actual regime is thus one where electricity is rationed to farmers; this assumption was the basis for the discussion in section 4. This also opens up for the practical possibility that "influence" activities can be of major importance, as was discussed in section 5. We will in this section ignore influence activities, and assume (as before) that agricultural consumers in group 1 have zero productivity of additional electricity at the margin in a rationing solution (V_1' = 0), as this group is, by assumption, not effectively rationed.

The marginal value of water supply can then be written as

(31) $$\frac{\partial U}{\partial E} = (1-\alpha)(\tau\phi_2 k - \phi_a h) + \alpha G' - c$$

[8] For a related analysis of power utility incentives see Strand (2012). It is here pointed out that multiple equilibria may arise when the public's willingness to pay for utility services is a function of expected service quality, which in turn may be a function of payment for services.

where $k = (1-\beta)V_2'$ as before, while we have defined

(32) $$\phi_a = \beta\phi_1 + (1-\beta)\phi_2$$

as the average efficiency of electricity use among farmers.

We are interested in how electricity rationing combined with a zero electricity price may affect incentives of farmers to invest in more efficient pumping equipment. Assuming that $V_1' = 0$ in this case (group 1 is "oversupplied" with electricity), we find the following first-order condition for group 2 farmers (who are effectively rationed):

(33) $$\phi_2' = \frac{1}{\tau E_2 V_2'}$$

For individual farmers, the groundwater externality cost does not figure in the decision to invest in pumps. The lack of this parameter contributes to a lower private marginal value of pumping at equilibrium, and greater than socially optimal private investments in pumps. A high electricity allocation E_2 also, in itself, draws in the same direction. The reason is that more available electricity (less strict rationing) makes it more worthwhile to invest in pumps so as to better utilize the greater amount of electricity supply available. But, on the other hand, a high allocation W_2 is likely to be correlated with a low marginal value V_2' of electricity. This works in the opposite direction since it reduces the marginal value of groundwater extraction, and thus pump efficiency, for given E_2. It is, in fact, the product of E_2V_2' that matters: when this product is at least as high in the rationing case as in the optimality case of section 6, pump efficiency choice is greater in the rationing case. We see that the parameter τ (representing "supply quality" by the electricity supplier, for given amount of electricity supplied) also matters. Higher τ increases farmers' value of a given electricity supply which here makes them invest more in pumps.[9] We cannot say in general whether these investments will be higher or lower than optimal. It could however easily be the case that, in a solution with rationing and zero electricity price, some major group of farmers (here, group 2) over-invests in pump equipment.

The height of the water table has conflicting effects in this context. For given amount of electricity available to group 2 farmers through rationing, a lower water table implies that more electricity is used to pump a given amount of water, so that water extraction is reduced, and the shadow value of electricity use reduced. But this also makes electricity scarcer among farmers, as electricity must be used more efficiently in order to achieve the same crop levels. Overall, the impact on incentives of farmers of installing extra pumping equipment is ambiguous in general. Most likely however the aforementioned cost effect will dominate and thus reduce such incentives.

8. Summary of inefficiency sources, and final comments

We will now, based on the foregoing analysis, compile a brief list of what we believe are the most important sources of inefficiency in the allocation of electricity to the agricultural sector in a system corresponding to our model. The main elements are as follows:

[9] The direction of this effect is not immediately obvious. If delivery quality is represented by the number of hours per day of electricity supply, more hours of supply could in principle reduce the need for pumping capacity as a given amount of pumping could be spread over a longer time span.

a) Excessive extraction of groundwater, so that the marginal return of groundwater, when applied in agriculture, does not cover the total marginal costs (the sum of electricity provision costs, and the shadow value of groundwater). The main source of this distortion is the low price of electricity paid by the agricultural sector, and the common-pool nature of the groundwater resource. In the foregoing, we have simply taken the marginal groundwater externality (per unit of electricity consumed by farmers) as given. In an accompanying paper (Strand (2010)), h (comprising the shadow value of remaining water in the aquifer plus the marginal cost of pumping) is derived from first principles, under simplifying assumptions. It is there shown that h tends to vary with the level of the groundwater table, and takes lower values when the table is lower. This follows from the obvious fact that the amount of electricity required to pump one unit of groundwater is greater when the water table is lower. Since the marginal externality cost per unit of water extracted is (more or less) invariant to the level of the groundwater table, this externality cost most be distributed over a larger number of electricity units for a lower table, and hence itself be smaller. Such an argument must however recognize that the number of electricity units required to extract one unit of groundwater varies with depth to the groundwater table (pumping height), which is not recognized in the models of this note.

b) Inefficient allocation of electricity among agricultural users, who are essentially all rationed. The marginal product of electricity consumption is then likely to vary substantially between farmers, with some having a high and others a very low marginal value. This problem is diminished if there exist markets for reselling of extracted water among farmers (with and without wells).

c) Other inefficiencies in the use of electricity among farmers. One is lack of incentive to install equipment that would serve to increase the efficiency of electricity use. We have however also seen that inefficient extraction can represent a two-edged sword. When the allocation of electricity to farmers is given, higher efficiency in its use may lead to more groundwater extraction and thus greater negative externalities, which may reduce welfare.

d) Inefficient choice of crops when crop choice depends on water availability. In some cases and for some farmers, water will be more plentiful than in the efficient allocation (when the electricity pumping price is very low and electricity is not heavily rationed), and in other cases less plentiful (when electricity is very heavily rationed). Essentially, the inefficiency will take the form that farmers select too water-intensive crops when electricity (and water) is plentiful, and the opposite when electricity is heavily rationed.

e) Diversion to illicit use of some part of the electricity supply intended for agricultural use. Such diversion may, as an isolated phenomenon, be undesirable. Moreover, within the group of illicit users electricity allocation is likely to be sub-optimal (with some users have higher marginal utilities than others). Illicit diversion however also represents a two-edged sword, given that farmers are initially over-supplied. Since more illicit consumption of electricity then might lead to less agricultural consumption, negative externalities due to less groundwater being extracted could then be reduced (although this would of course not be the intention).

f) Excessive influence activities in the agricultural sector to induce (possibly, bribe) power utility officials to increase agricultural supply, and to reduce illicit use (including direct power losses). Such activities are socially costly, and could in addition involve increased externality costs as noted under point d). Similar influence activities can be exerted by illicit electricity consumers, to increase illicit use. Such activities are directly countervailing to the former. A “zero-sum game” situation may easily arise, where different types of influence activities have impacts in opposite directions, with no overall major change in outcome.

g) Inefficient incentives of the power utility to stem losses, when neither the overall utility (it bottom line) nor its employees are directly rewarded for this; see also d) and e).

h) Insufficient incentives of the power utility to provide good and reliable service to the agricultural sector. Such lack of incentives is exacerbated by the lack of payments for electricity delivery (as also stressed by Strand (2011)).[10] Above, this loss takes the form of directly reduced utility of agricultural users, for a given power supplied.

In sum, these various misallocations make up a major, and somewhat confusing, set of overall distortions, when the entire situation for this system is compared to a (hypothetical) “first-best” situation. Not all distortions go in the same direction; and some of the distortions tend to partly eliminate the adverse effects of other distortions.

An important next step in this analysis would be to obtain a better empirical understanding of the quantitative distortions caused by inefficient electricity pricing and supply, in situations such as those facing Indian farmers. Initiating that empirical work in turn requires additional effort to gather the disaggregated empirical data necessary for estimating the various relationships, which is an important issue for future research. This requires additional surveys to be done of farmers’ water use and pumping practices; willingness to pay e.g. in terms of higher water prices for better service, including the value of water meters; surveys of additional features such as how crop choice might depend on effective water prices; and various features of pumping equipment. It would also be important in such surveys to include groups of farmers with water metering, wherever feasible. Such data should also include supply side data, and data for water table depth and magnitude of groundwater extraction externality, which are likely to vary significantly by location.

[10] See also e g Bardhan and Mookherje (2006), Muhairwe (2009), and Walker et al (1999).

Literature:

Banerji, A., Meenakshi, J. V. and Khanna, G. (2006), Groundwater Irrigation in North India: Institutions and Markets. Kathmandu, Nepal: SANDEE Working Paper no 19-06.

Bardhan, P. and Mookherjee, D. (2006), Decentralization and accountability in infrastructure delivery in developing countries. *The Economic Journal*, 116, 101-127.

Birner, Regina, Surupa Gupta, and Neeru Sharma (2010), The Political Economy of Agricultural Policy Reform in India. The Case of Fertilizer Supply and Electricity Supply for Groundwater Extraction. Manuscript, IFPRI, New Dehli.

Briscoe, J. and Malik, R. P. S. (2006), *India's Water Economy: Bracing for a Turbulent Future*. Oxford and New York: Oxford University Press.

Dubash, N. K. (2005a), The New Regulatory Politics of Electricity in India: Independent, Embedded or Trascendent? Working Paper, National Institute of Public Finance and :Policy, New Delhi.

Dubash, N. K. (2005b), The Electricity-Groundwater Conondrum: The Case for a Political Solution to a Political Problem. Working paper, National Institute of Public Finance and Policy, New Dehli.

Muhairwe, W. T. (2009), *Making Public Enterprises Work*. London: IWA Publishing.

Ramachandra Murthy, K. V. S. and Ramalinga Raju, M. (2009), Analysis on Electrical Energy Consumption of Agricultural Sector in Indian Context. ARPN Journal of Engineering and Applied Sciences, 4 no 2, 6-9.

Ray, Binayak (2008), *Water: The Looming Crisis in India.* Plymouth, UK: Lexington Books.

Reddy, V. Rathna (2005), Cost of Resource Depletion Externalities: A Study of Groundwater Overexploitation in Andhra Pradesh, India, *Environment and Development Economics*, 10, 533-566.

Shah, Tushaar (2009), *Taming the Anarchy. Groundwater Governance in South Asia*. Washington DC: RFF Press.

Shah, T., Molden, D., Sakthivadivel, R. and Seckler, D. (2000), *The Global Groundwater Situation: Overview of Opportunities and Challenges.* Colombo: International Water Management Institute.

Strand, Jon (2010), The Full Economic Cost of Groundwater Extraction. World Bank Policy Research Working Paper, WPS 5494, December 2010.

Strand, Jon (2012), Low-Level and High-Level Equilibrium in Public Utility Services. *Journal of Public Economics*, 96, 163-172.

Vaidyanathan, A. (2006), *Inda's Water Resources. Contemporary Issues in Irrigation*. Oxford and New York: Oxford University Press.

Walker, I. et.al. (1999), Reform efforts in the Honduran water sector. In Savedoff, W. and Spiller, P. (eds.), *Spilled Water: Institutional Commitment in the Provision of Water Services.* Washington DC: Inter-American Development Bank, pp. 35-88.

World Bank (2005), *India's Water Economy: Bracing for a Turbulent Future*. Washington DC. The World Bank.

World Bank (2010), *Deep Wells and Prudence: Towards Pragmatic Action for Addressing Groundwater Overexploitation in India*. Washington DC: The World Bank.

Appendix: List of variables and symbols used in the model, with explanations

E = total electricity supply, E_i = electricity supply to group i (= 1,2)
α = share of total electricity supply that goes to illicit users (including losses)
U = objective function (to be maximized by the public sector)
V_i = utility of electricity consumption for group i (= 1,2).
h = shadow value of standing groundwater including pumping cost, per unit
c = marginal electricity supply cost
G = value of electricity consumption for illicit users
β = fraction of farmers that belong to group 1, 1-β = fraction in group 2 (fractions in terms of electricity consumption)
k = marginal value of electricity consumed by group 2, when rationed ($k < c+h$)
B = effort by farmers to have the illicit electricity consumption share reduced, through influence activities directed at the utility.
H = effort by illicit electricity consumers to increase their illicit electricity consumption, through influence activities directed at the utility.
τ = parameter indicating the marginal value of electricity for farmers, in response to effort from utilities
Z = effort by the power utility to affect farmers' value of electricity (τ)
Q = cost incurred by the power utility to reduce the share of illicit electricity consumption
Φ_i = efficiency in electricity use of farmers per unit of electricity consumed, for farmers in group i (=1,2)
Φ_a = average efficiency in extracting groundwater through pumping, average over all farmers
C_i = cost to farmers of implementing private efficiency improvements for groundwater pumping